EE-434 Power Electronics

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Overview

- Controlled Half-Wave Rectifiers - Resistive load
- Controlled HWR- Resistive-Inductive load

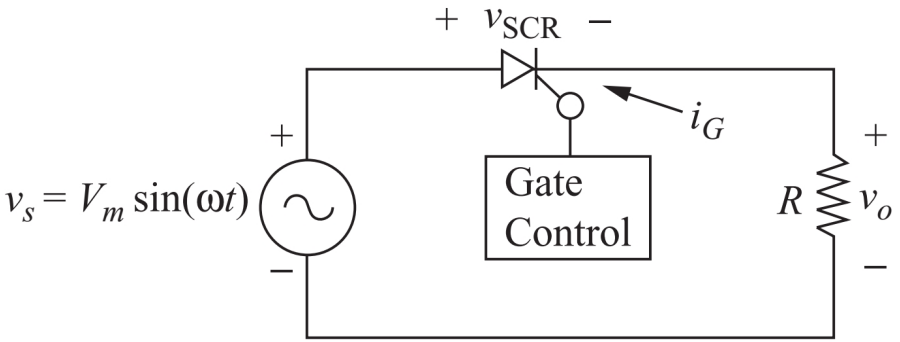
CHWR — Resistive load

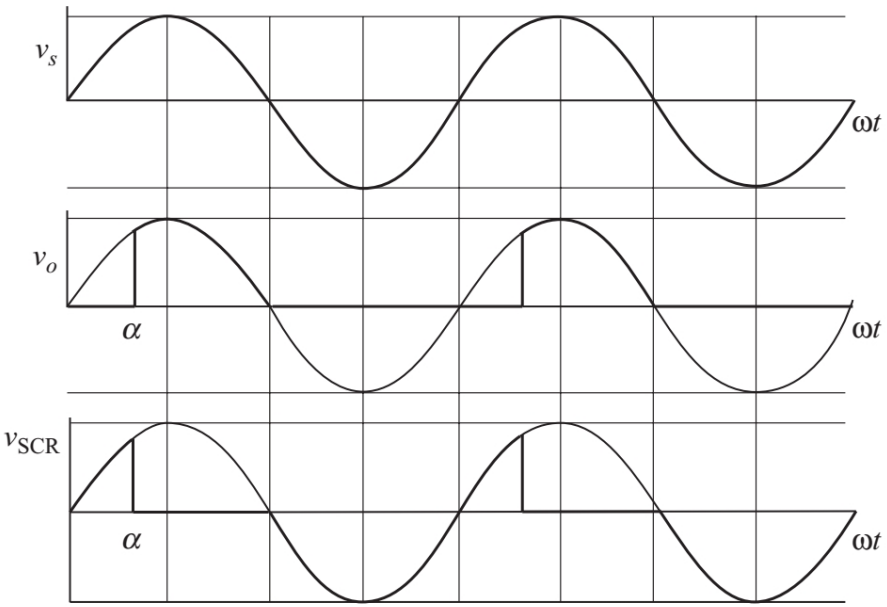
The rectifier output can be controlled by using an SCR or any other controlled device.
SCR conducts in two conditions.

- The SCR must be forward biased ($V_{AK} > 0$)
- Gate current applied to the SCR

Analysis trend similar like an uncontrolled rectifier will be followed.

Controlled HWR — Resistive load





At $\omega t = \alpha$, the gate signal is applied. α is called the delay angle and it varies between $0 < \omega t < 180°$.

Average voltage across load resistor is

$$V_o = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m sin(\omega t) d(\omega t) = \frac{V_m}{2\pi}(1 + cos\alpha) \quad (1)$$

Controlled HWR — Resistive load

Power absorbed by the resistor is $\frac{V_{rms}^2}{R}$. The rms voltage across the resistive load is

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} v_o^2(\omega t)d(\omega t)} \tag{2}$$

Using (1), the above equation can be modified as

$$V_{rms} = \frac{V_m}{2}\sqrt{1 - \frac{\alpha}{\pi} + \frac{sin(2\alpha)}{2\pi}} \tag{3}$$

CHWR — Resistive-Inductive load

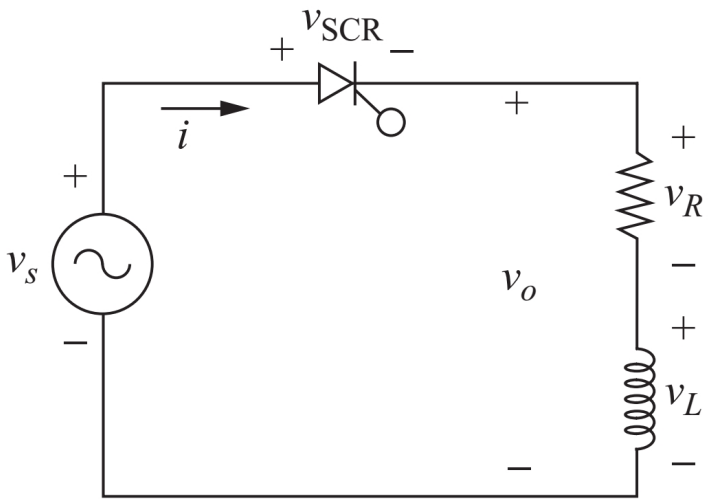
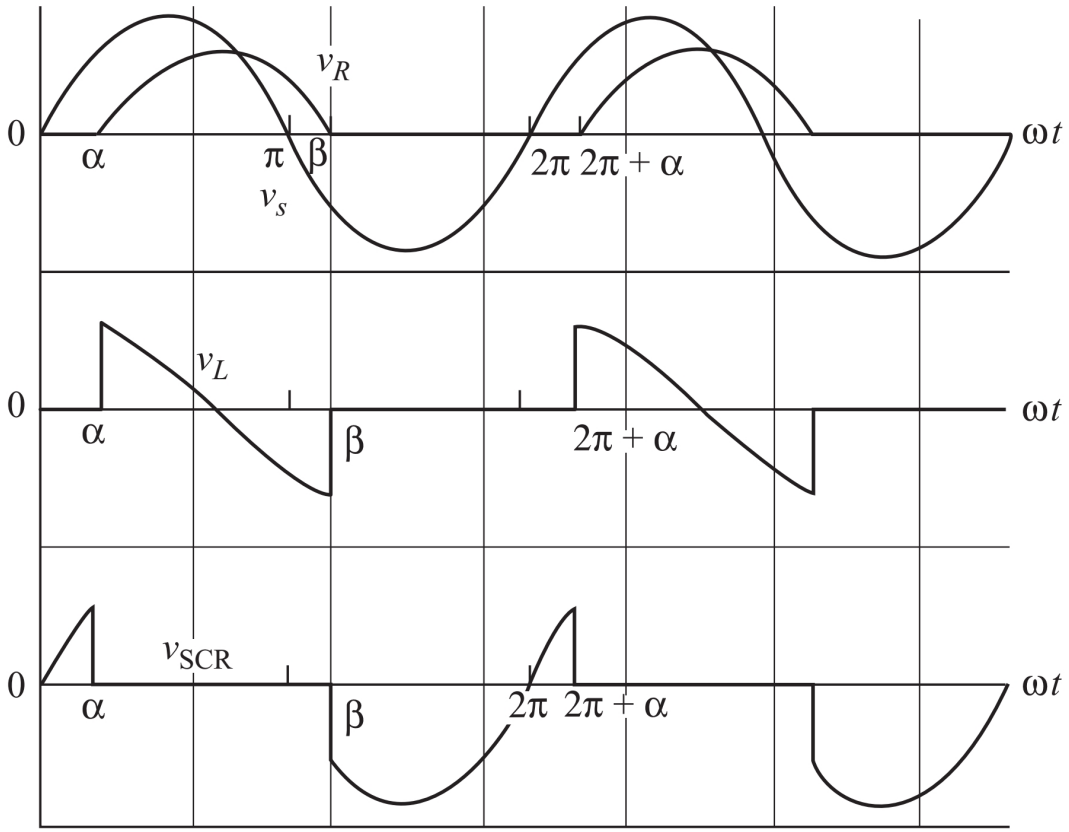


Figure: Circuit diagram



CHWR — Resistive-Inductive load

The analysis is similar like a diode based system.
Current is sum of forced and natural response.

$$i(\omega t) = i_f(\omega t) + i_n(\omega t) = \frac{V_m}{Z} sin(\omega t - \theta) + Ae^{-\omega t/\omega\tau} \tag{4}$$

This is a general solution. To make it particular, initial condition is applied i.e., i(α)=0

$$i(\alpha) = 0 = \frac{V_m}{Z} sin(\omega t - \theta) + Ae^{-\alpha/\omega\tau} \tag{5}$$

$$A = \left[-\frac{V_m}{Z} sin(\alpha - \theta) \right] = e^{\alpha/\omega\tau} \tag{6}$$

After substituting this and simplifying

$$i_{(\omega t)} = \begin{cases} \frac{V_m}{Z} \left[sin(\omega t - \theta) - sin(\alpha - \theta) e^{(\alpha - \omega t)/\omega\tau} \right] & \text{for } \alpha \leq \omega t \leq \beta \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

CHWR — Resistive-Inductive load

The extinction angle β is defined as the angle at which the current remains to zero. When $\omega t = \beta$,

$$i(\beta) = 0 = \frac{V_m}{Z}\left[sin(\beta - \theta) - sin(\alpha - \theta)e^{(\alpha-\beta)/\omega\tau)}\right] \tag{8}$$

This angle $\beta - \alpha$ is called the conduction angle γ.
The average (dc) output voltage is

$$V_o = \frac{1}{2\pi}\int_{\alpha}^{\beta} V_m sin(\omega t)d(\omega t) = \frac{V_m}{2\pi}(cos\alpha - cos\beta) \tag{9}$$

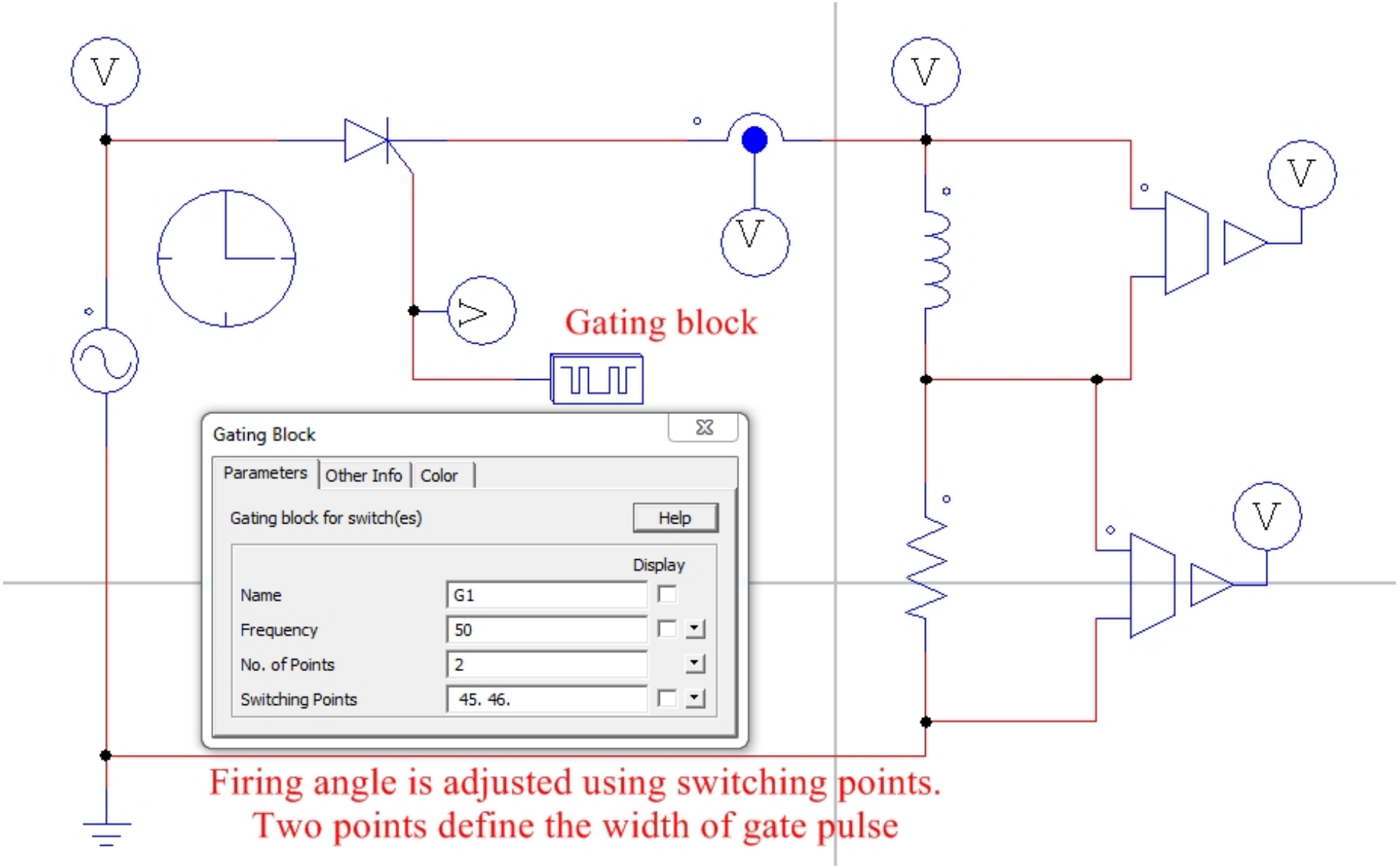
Current waveshape is different and therefore, the average current is

$$I_o = \frac{1}{2\pi}\int_{\alpha}^{\beta} i(\omega t)d(\omega t) \tag{10}$$

Power absorbed by the load is $I_{rms}^2 R$, and

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\beta} i^2(\omega t)d(\omega t)} \tag{11}$$

CHWR — Resistive-Inductive load simulation



CHWR — Resistive-Inductive load simulation

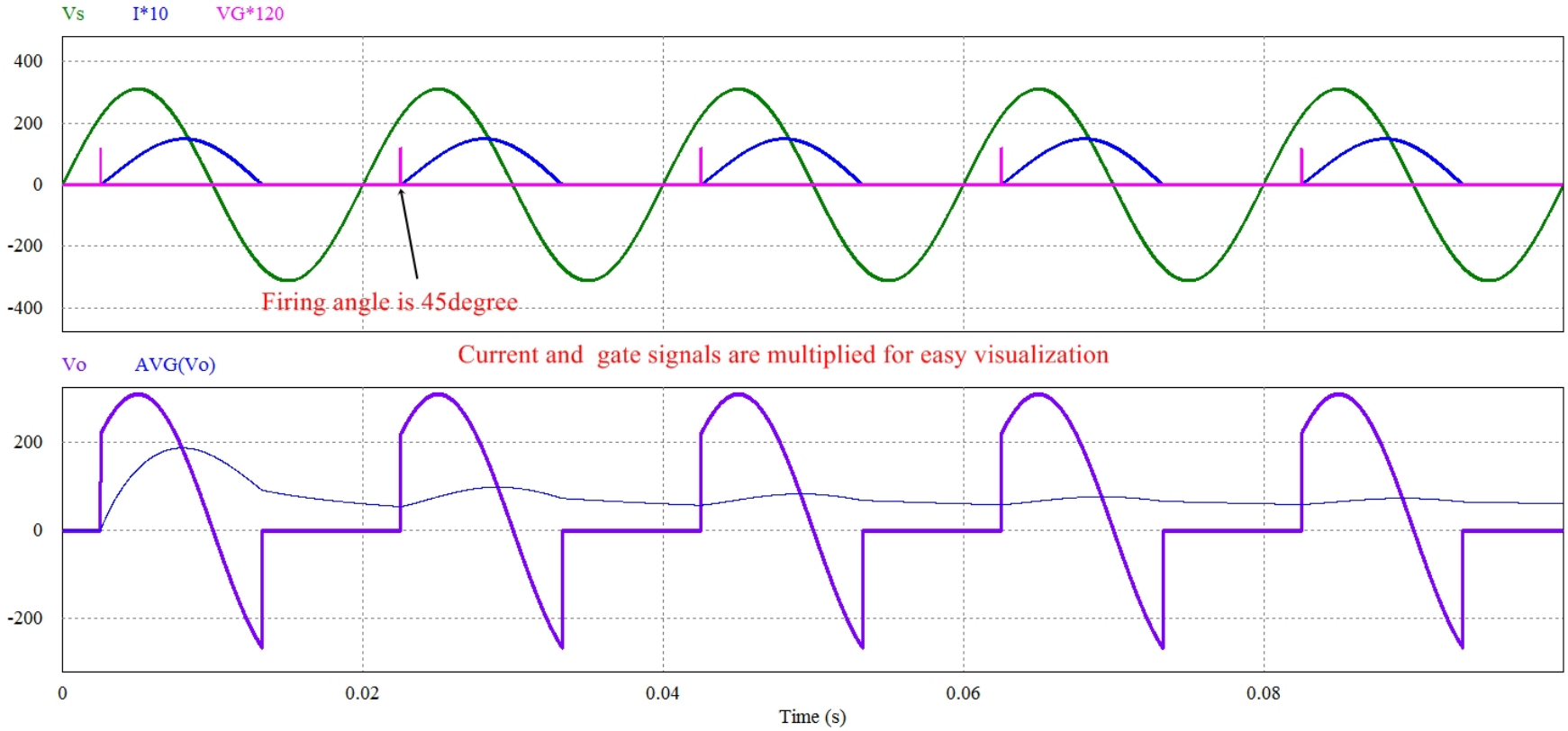
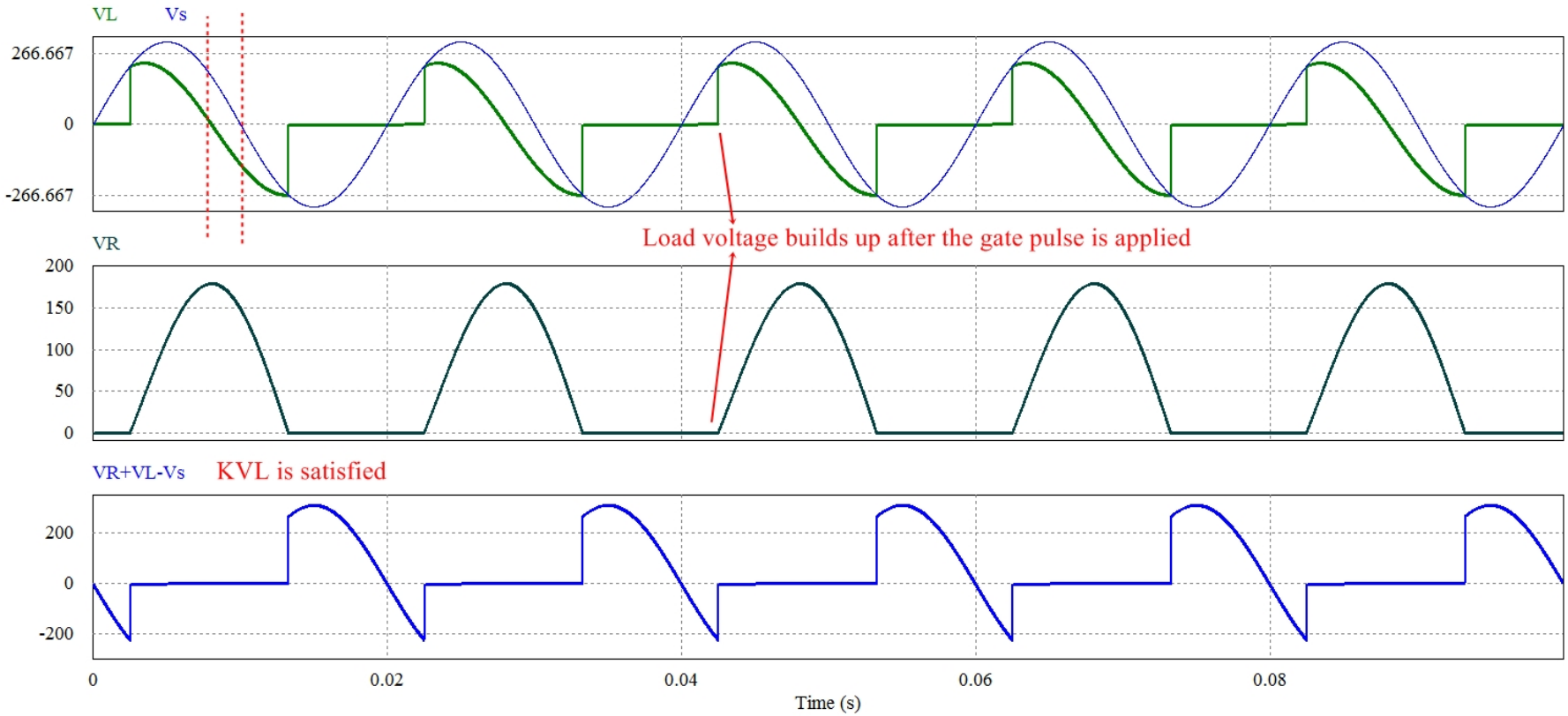


Figure: Simulation results of a CHWR in PSIM

Input is 220V at 50 Hz. R=12 and L=60m. Firing angle is 45°.

CHWR — Resistive-Inductive load



KVL is satisfied for the conduction duration. When the conduction stops, all the input voltage is blocked by SCR and can be seen in the bottom most graph.

Example 3-11 CHWR-RL

For the half-wave controlled rectifier of R=20Ω, L=0.04H, and V_{rmw}=120 V at 60Hz. Determine (a) current expression (b) the average current, (c) the power absorbed by the RL load, and (d) the power factor.

Solution:

For this circuit following parameters are calculated

$$Z = [R^2 + (\omega L)^2]^{0.5} = 25.0\Omega \tag{12}$$

$$\theta = tan^{-1}(\omega L/R) = 20.7^\circ = 0.646 rad \tag{13}$$

$$\omega t = (\omega L/R) = 0.754 rad \tag{14}$$

$$\alpha = (45^\circ) \times \frac{\pi}{180} = 0.785 rad \tag{15}$$

Using (7) the current expression can be obtained

$$i(\omega t) = 6.78 sin(\omega t - 0.646) - 2.67 e^{-\omega t/0.754} \tag{16}$$

The above equation is valid from α to β. β is found numerically by setting above equation to zero and solving for β. Conduction angle is $\beta - \alpha$=3.01rad=172°

Example 3-11 CHWR-RL

Average current is determined from (10)

$$I_o = \frac{1}{2\pi}\int_{0.785}^{3.79}[6.78sin(\omega t - 0.646) - 2.67e^{-\omega t/0.754}]d(\omega t) = 2.19A \quad (17)$$

To find power, the rms current is calculated

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_{0.785}^{3.79}[6.78sin(\omega t - 0.646) - 2.67e^{-\omega t/0.754}]^2 d(\omega t)} = 3.26A \quad (18)$$

The power absorbed by the resistor is

$$P = I_{rms}^2 R = (3.26)^2(20) = 213W \quad (19)$$

Note that average power absorbed by the inductor is zero.
Power factor is given by

$$pf = P/S = \frac{P}{V_{s,rms}I_{s,rms}} = \frac{213}{(120)(3.26)} = 0.54 \quad (20)$$